CRACK ORIGIN AND DETECTION IN THIN CRISTALLYNE SOLAR CELLS IN A PRODUCTION LINE

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ABSTRACT: In order to reduce cost and make up for the rising price of silicon, silicon wafers are sliced thinner and wider, leading to weaker wafers and increased breakage rates during fabrication process. In this work we have analysed different cracks origins and their effect on wafer's mechanical strength. To enhance wafer's strength some etching methods have been tested. Also, we have analysed wafers from different points of an entire standard production process. Mechanical strength of the wafers has been obtained via the four line bending test and detection of cracks has been tested with Resonance Ultrasonic Vibration (RUV) system, developed by the University of South Florida.
Keywords: Crack detection, Cost reduction, Manufacturing and Processing.

1 PURPOSE

Crystalline silicon is the most widely used material in the photovoltaic industry. In the last few years the thickness of as-cut wafers has decreased dramatically from 330µm to 240µm and it is estimated to continue decreasing at 30µm/year. In laboratory scale wafers are sliced at 120µm or even thinner [1]. This reduction of the wafer thickness decreases the fabrication yield because of the rising of breakage ratio.

This paper discuses the origin of the cracks, their effect on wafer strength and a way to detect them. This work is based on results obtained from Isofoton's standard industrial line.

2 CRACK ORIGIN

Cracks present in a wafer may have two different origins. First, the cause can be intrinsic resulting from the damage produced during the wire sawing. Second, the source can be extrinsic as damage produced during handling or processes that can stress the wafer.

It is well known that the wire sawing process produces surface damage on wafers [2][3]. Wafer producers admit a surface damage up to 14 µm deep [4] but it's suspected that there is a deeper damage below the surface. J. Barredo et al. [5] suggest a subsurface damage up to 30 µm deep. To remove the surface damage, chemical or mechanical etching is used, however, chemical etching has shown better results [6].

2.1 Cracks generated in a production line

While intrinsic damage of the wafer is hard to avoid, solar cells manufacturers have to pay special attention to their production equipment in order not to damage the wafers.

To measure the extrinsic damage generated during the solar cell process, two sets of thin 125x125mm^2 monocrystalline silicon wafers were introduced in a standard production line. These sets of wafers were 125µm and 150µm thick, respectively, whereas the production line was prepared for 240µm thick wafers. Results show that crack formation is related more to the wafer handling process (fig.1) rather than the cell processing.

Thin wafers must be handled with special care so that optical aligning and vacuum handlers are capable of carefully managing them. Pushers, lateral friction points, mechanical positioners and any strike in the edge of the wafer could be a crack source that leads to breakage.

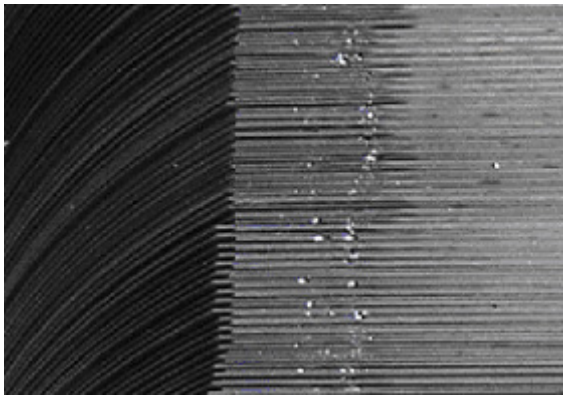

Figure 1: Wafers damaged by handling tools

High stress processes (fig.2), like metallization firing, soldering or laminating, are not necessarily processes that generate cracks. They don't usually damage the wafer but, if the wafer is already damaged, generated stress can propagate the crack so far as to break it. This shows the necessity of having a good wafer crack detection system before beginning these processes.

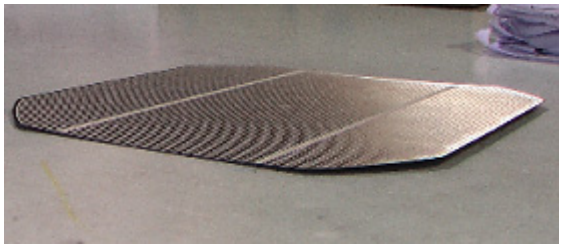

Figure 2: Strain generated by process

This experiment resulted in a greater than 80% yield when avoiding especially harmful handling procedures. This shows that industrially available manufacturing process is able to produce 125µm thick wafers.

3 CRACK EFFECTS ON WAFER MECHANICAL STRENGTH

It is already known that cracks have a crucial effect on silicon wafers' mechanical strength of the silicon wafers and some studies have related the mechanical strength of the wafer with the critical crack length [6].

The four line bending test has been chosen to carry out the experimental study. In this way, edge and surface defects are taken into account because the moment applied is constant in the analyzed region [7]. Knowing that the mechanical strength that characterizes a wafer is independent of its thickness for a reference area [5], this data lets us know the probability of breakage for every handling procedure.

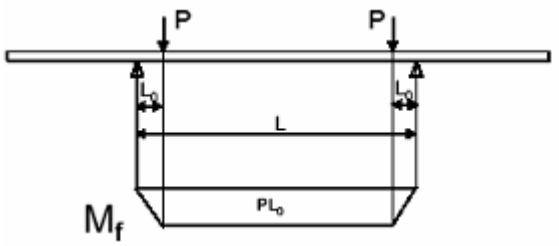

Figure 3: Sketch of the simplified model of four line bending test

Figure 4: Four line bending tester

For this experiment, wafers with different etching treatments (chemical and mechanical) have been analyzed. Also we have analyzed wafers from different points of the production process.

Test results show dependence between decreased thickness and mechanical strength of the wafer, but this dependence changes form one etching method to another. The best results are obtained with chemical etching (NaOH) and the mechanical strength of the wafer is enhanced with a longer etching process. Above a certain value of decreased thickness, around 30 microns per face, the bending strength remains constant (fig.5). With this decrease, the surface cracks caused by the sawing process have been eliminated. Any other type of etching like mechanical etching or chemical etching with acid $HF\text{-}HNO_3$ shows worse results.

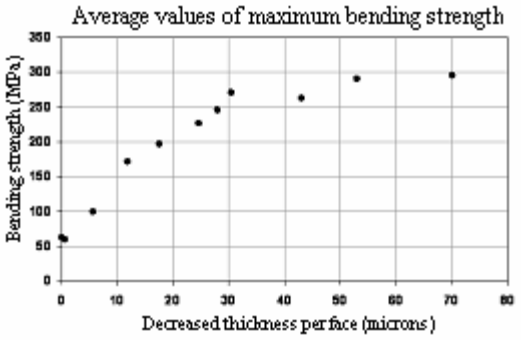

Figure 5: Bending strength with decreased thickness

Other steps of the process observed, like texturing and diffusion, do not show any important change in the mechanical strength of the wafers.

4 CRACK DETECTION

In order to detect the presence of cracks in the wafers we have use the RUV technique [8]. This technique excites a wafer, through a vacuum coupled high frequency piezoelectric transducer, with ultrasonic vibrations of a range of frequencies. The response of the wafer is taken through an ultrasonic probe and the resonance peaks are analysed.

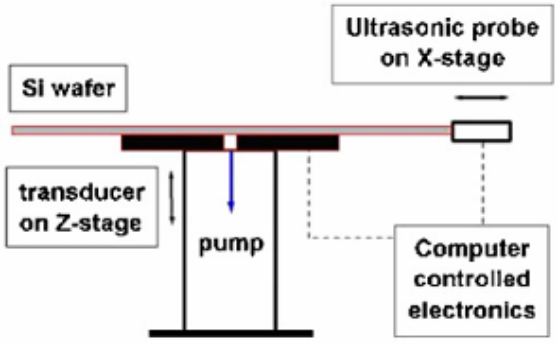

Figure 6: Schematic of the RUV system

If a wafer has a crack its resonance peak frequency shifts down, the peak becomes wider, and its amplitude decreases. The responses of an undamaged wafer and a wafer with a crack can be seen in figure 7.

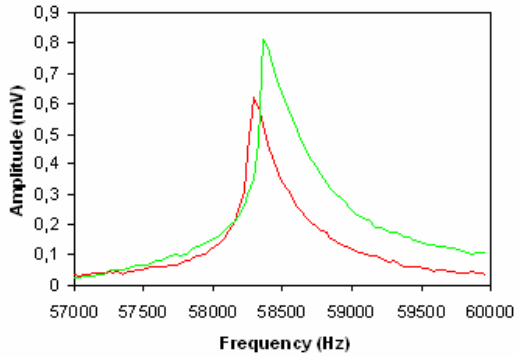

Figure 7: Resopnse of two 125x125mm monocrystalline silicon wafers. The red trend shows a damaged wafer.

A tracking of a set of 50 wafers has been done along the fabrication process measuring them with this technique and data of central frequency of resonance peaks has been obtained (fig. 8). In our measurements, this data has the most reliable information to detect damaged wafers.

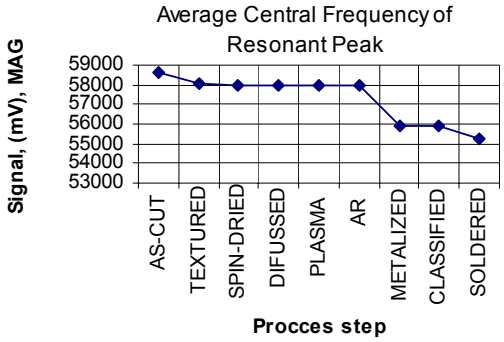

Figure 8: Average central frequency of RUV peak

In the fabrication process three shifts in central frequency of RUV peaks have been seen. These shifts are related to physical changes in the wafer. The first shift occurs after the texturing process, the second shift appears after the deposition and firing of metal contacts, and the last one can be seen after soldering.

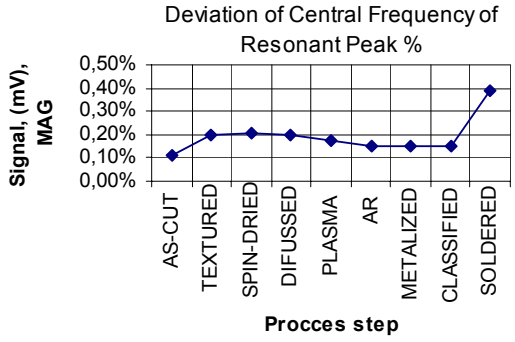

Figure 9: Standard deviation of central frequency of RUV peak

The limit of this detection method is the size of the crack. If the shift of the frequency of the cracked wafer is smaller than the maximum allowed shift, the crack won't be detected. Fortunately the deviation from one wafer to another is very small (fig. 9) and the maximum allowed shift can be set to a very small value. Before soldering, the typical deviation of central frequency increases and the maximum allowed shift has to be set in a bigger value, increasing the minimum size of crack detectable.

5 CONCLUSIONS

Surface damage generated during wire sawing and cracks induced during wafer handling and processing affects its mechanical strength.

An adequate elimination of the surface damage causes a dramatic increase in the wafer's mechanical strength. Other processes, like texturing, don't have any effect on wafer strength.

RUV technique can be an adequate method for in line crack detection at any point of the industrial process.

A proper handling and production process is able to produce cells down to 125 microns thick with high yields using equipment and production lines available in the market.

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